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LOCALLY GENERATED MODEL OUTPUT STATISTICS AT WFO COLUMBIA, SOUTH CAROLINA

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1. INTRODUCTION

In an effort to supplement the centrally produced (FWC and FAN) Model Output Statistics (MOS), two sets of maximum and minimum temperature equations for Columbia, SC (CAE) were developed using multiple linear regression. While the local equations produced some improvement over the centrally produced MOS, a simple average of the results of the local equations and MOS resulted in the best forecasts.

We have come to recognize that blending or developing a consensus of forecast guidance is often superior to the individual guidance forecasts that compose the consensus (Fritsch et al. 2000). The primary goal of this paper is to document an improvement in temperature forecasts by using an average of local techniques and national guidance. This additional guidance has helped us achieve our goal as an office to improve upon the FWC MOS mean absolute error (MAE) by more than 10 percent and maintain it from 1998 through 2000 (See Fig. 1).

2. METHODOLOGY

A multiple linear regression equation contains a single predictand, y , and several predictor variables, x. The regression equation takes on the form $y = b_0 + b_1 x_1 + b_2 x_2 + ... + b_k x_k$. Each of the predictor variables, x_k has a coefficient, b_k. The intercept (regression constant) is denoted as b_0 (Wilks 1995; Collins 2000).

The dependent variable or predictand in this study was the daytime maximum and nighttime minimum temperature at CAE. Separate maximum temperature equations were developed for daytime periods verifying 24-h and 48-h after 0000 UTC, and 36-h after 1200 UTC. Separate minimum temperature equations were developed for the nighttime periods verifying 36-h after 0000 UTC, and 24-h and 48-h after 1200 UTC. For one set of equations (LOC1), predictor data consisted of both Eta model forecast sounding data at CAE, extracted from a local archive of BUFKIT data (Niziol and Mahoney 1997), and NGM based MOS (FWC) maximum and minimum temperature forecasts for CAE. A second set of equations (LOC2) was developed using predictor data solely from the Eta model. The data archive used in the equation development covered the period from April 1997 through February 2000. Separate equations were developed for each of the four seasons. The spring season was defined as March through May; Summer was defined as June through August; Fall was defined as

September through November; Winter was defined as December through February.

A commercially available statistical software package was utilized to perform variable selection and multiple linear regression to arrive at the local forecast equations. An explanation of these processes can be found in Draper and Smith (1998) and Wilks (1995). The objective of the variable selection process was to maximize the amount of variance in the predictand explained by the predictor variables (R^2 statistic) while at the same time minimizing the amount of bias in the resultant temperature forecasts (Mallows Cp statistic). Variable selection was terminated when it was determined that this objective was met. Scatter plots of the residuals were examined to determine if they behaved in a manner consistent with the assumptions of multiple linear regression. Specifically, they should be normally distributed and exhibit nearly equal variance along the range of predicted values (homoscedasticity). When these conditions were not met, a transformation of the dependent variable was required to render the residuals homoscedastic and normally distributed. In most cases where a transformation was required, a logarithmic transformation was suitable. The forecast equations are listed in appendix II.

Consensus forecasts (CON) were an average of the NGM based MOS (FWC), the Aviation based MOS (FAN), LOC1 and LOC2. A local application was developed to format a bulletin containing all of the centrally produced guidance, the locally generated guidance, and the consensus forecasts. This bulletin is available to the operational forecast staff in real time.

3. VERIFICATION

Seasonal verification for the purpose of this study was carried out from the spring of 2000 through the winter of 2000-2001, i.e. the year subsequent to the developmental data set. The first through the third period temperature forecasts from the FWC, FAN, LOC1, LOC2, and CON were verified against the corresponding observed maximum and minimum temperatures from CAE by calculating the root mean squared error (RMSE) and the mean absolute error (MAE). The bias (BIAS) was also calculated to gain further insight into the error characteristics of each of the guidance tools. BIAS is equal to the mean algebraic error.

Hypothesis testing was conducted to determine if the MAE's of the guidance departed significantly from each other. To account for serial dependence, a two-sample t-test for correlated data was used at the 95% confidence level (Wilks 1995).

Local seminars were conducted on the use of MOS, ensembles, and verification in operational forecasting. Forecasters can view the monthly and seasonal verification results on the local Intranet to see which of the guidance models performs best in a general sense. Daily verification results are also available to the operational forecasters. So for example, if the weather pattern is in a given regime, the forecasters can look at the verification results for the past several days comprising that regime to see which guidance model has been performing best.

4. RESULTS AND CONCLUSIONS

The seasonal verification statistics are presented in Figs. 2 through 9. The results of the comparison tests are included in Table 1 and Table 2. A case is defined as a single forecast period within a single season. For the maximum temperature forecasts, CON improved over FWC and FAN for all the cases. Eleven of these cases were significant at the 95% confidence level and most predominant in the summer and fall seasons. All the summer 24-hr and 48-hr CON cases vs. the centrally produced MOS and the local schemes were significant at the 95% confidence level. All three fall season CON cases vs. FAN were significant at the 95% confidence level. CON improved over LOC1 and LOC2 for most of the cases. All the CON cases vs. LOC1 and LOC2 in the summer season were significant at the 95% confidence level.

LOC1 and LOC2 improved over FWC and FAN for most of the cases. Two LOC1 cases vs. FAN and one LOC2 case vs. FAN were significant at the 95% confidence level. However, none of the LOC1 and LOC2 cases vs. FWC were significant at the 95% confidence level. LOC1 and LOC2 did worse than the FWC and FAN mainly in the summer season with one FAN case vs. LOC2 significant at the 95% confidence level.

LOC1 improved over LOC2 for most of the cases. Two LOC1 summer cases vs. LOC2 were significant at the 95% confidence level.

For the minimum temperature forecasts, CON improved over FWC and FAN for all the cases. Twelve of these cases were significant at the 95% confidence level. All three summer and fall season CON cases vs. FAN were significant at the 95% confidence level. CON improved over LOC1 and LOC2 for most of the cases. Four CON cases vs. LOC1 and LOC2 were significant at the 95% confidence level with the majority in the winter season. All the winter 36-h CON cases vs. the centrally produced MOS and the local schemes were significant at the 95% confidence level.

LOC1 and LOC2 improved over FWC and FAN for most of the cases, especially in the summer and fall seasons. Two LOC1 cases vs. FWC and seven LOC1 cases vs. FAN were significant at the 95% confidence level. Two LOC2 cases vs. FAN were significant at the 95% confidence level. LOC1 and LOC2 did worse than the FWC and FAN mainly in the winter season, however none of the centrally produced MOS cases vs. the local schemes were significant at the 95% confidence level.

LOC1 improved over LOC2 for all the cases in the summer and winter. One LOC1 summer case vs. LOC2 was significant at the 95% confidence level.

In summary, CON showed improvement over all the other guidance. CON showed significant improvement over the FAN for a majority of the cases. CON also showed small biases. The errors of the models are not canceling each other, but rather since the errors of the models were often of opposite sign, the bias of the CON forecasts were small relative to that of the individual models (Fritsch et al. 2000). The locally derived guidance had lower mean absolute errors and root mean squared errors compared to the FWC and FAN for a majority of the cases, indicating a higher degree of accuracy. It is apparent from the results that developing local temperature equations can lead to improvement over the centrally produced MOS. Since CON outperformed both the centrally produced MOS and local schemes, it is a superior forecast. Further improvement may be possible if the bias of each model is removed before creating the CON (Fritsch et al. 2000).

5. FUTURE WORK

A maximum temperature equation was developed to forecast cold-air damming (CAD) conditions. The independent variables for the CAD equation were from the Eta model sounding data on days locally defined as CAD cases. CAD cases were defined as: An easterly or northeasterly flow at the surface, a southerly or southwesterly flow above the surface, overcast skies between 1200 UTC and

2400 UTC, at least a trace of precipitation from 1200 UTC to 2400 UTC, and a maximum difference between the 0600 UTC observed temperature and the 12-h maximum temperature from 1200 UTC to 2400 UTC of 12° F.

Since CAD cases are relatively rare, a sample data set sufficient in number for independent testing and verification is not yet available. As additional CAD cases accumulate, the CAD equation will be rederived and an attempt will be made at verification on an independent sample.

ACKNOWLEDGMENTS

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Appendix I

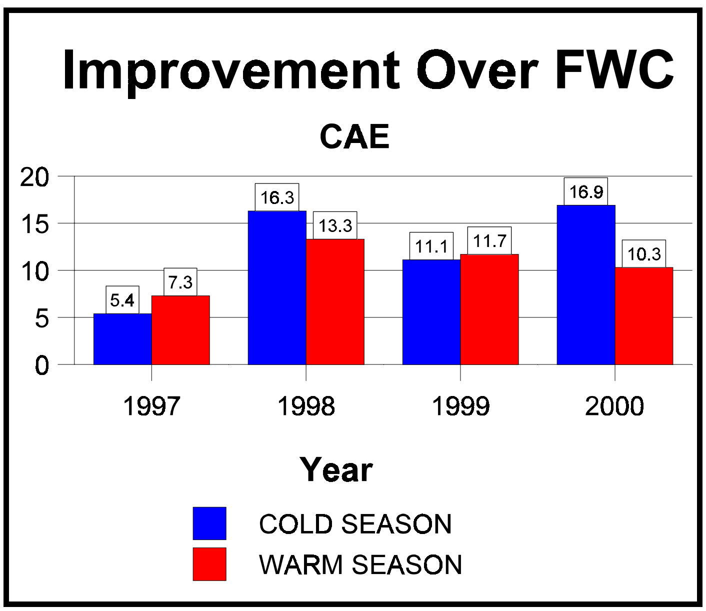
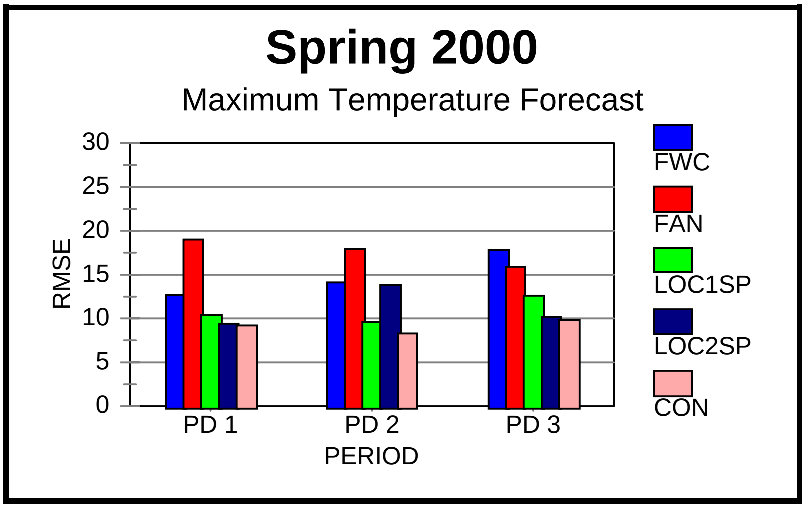


Figure 1. Percent improvement over FWC MOS Maximum / Minimum Temperature MAE (Mean Absolute Error) by CAE operational forecasts. Local equations and consensus were implemented operationally in 1998.

a)



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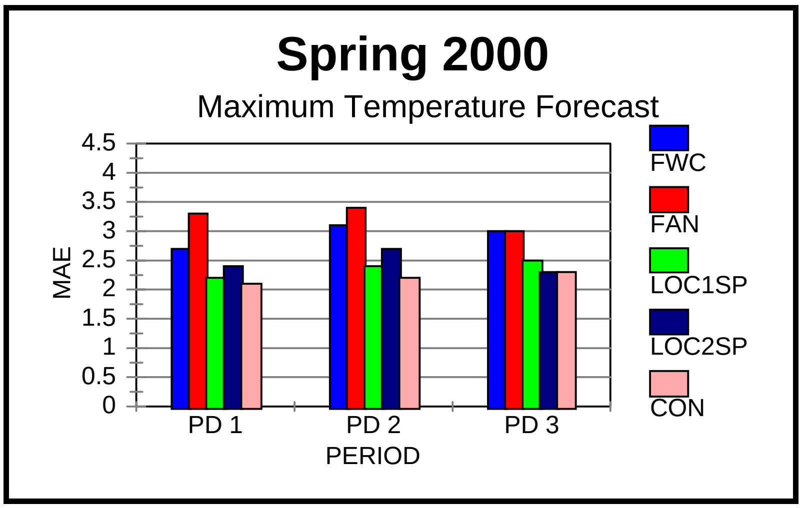

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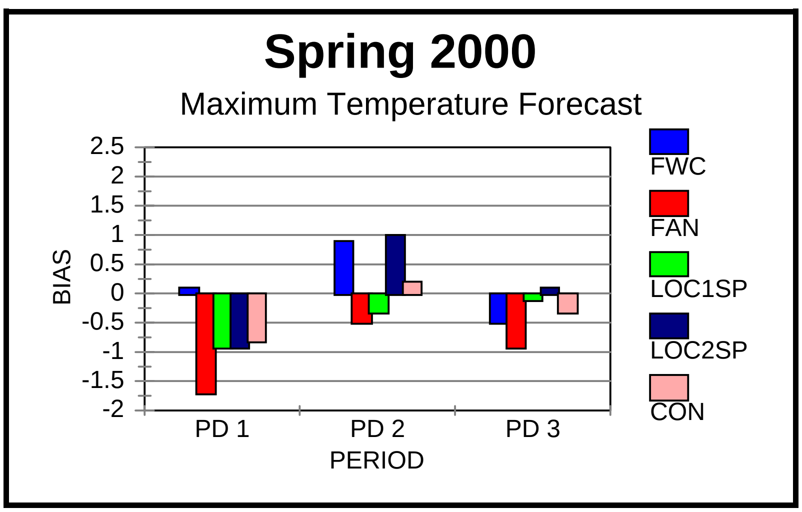
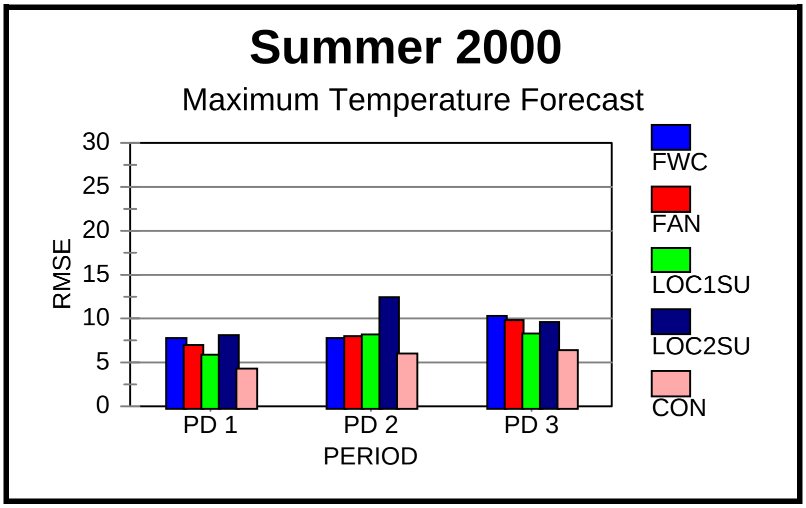


Figure 2. a) Root Mean Squared Error b) Mean Absolute Error c) Bias in degrees Fahrenheit. Maximum Temperatures - Spring (March - May)

a)



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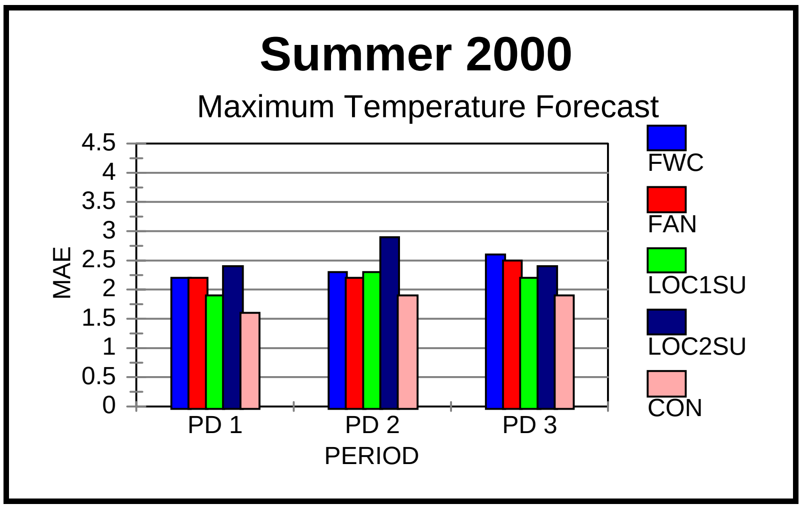

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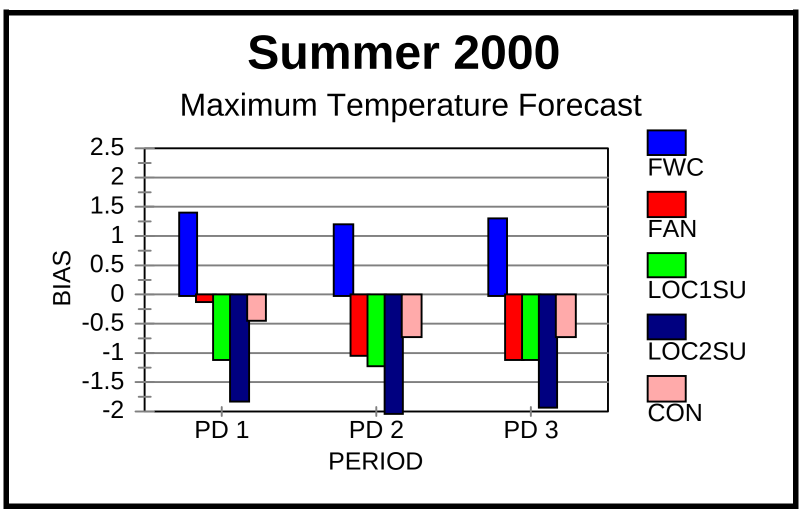


Figure 3. a) Root Mean Squared Error b) Mean Absolute Error c) Bias in degrees Fahrenheit. Maximum Temperatures - Summer (June - August)

a)

b)

c)

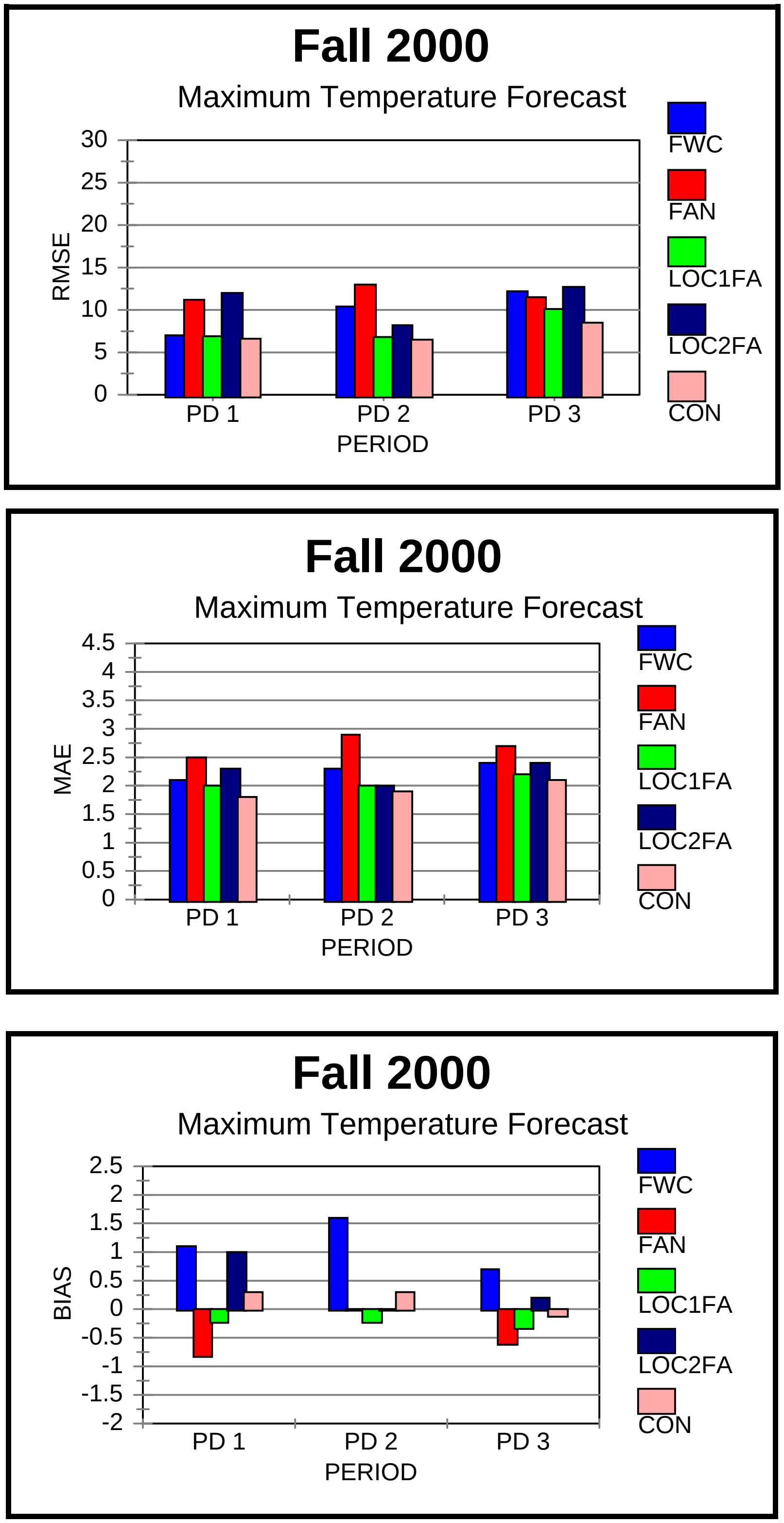
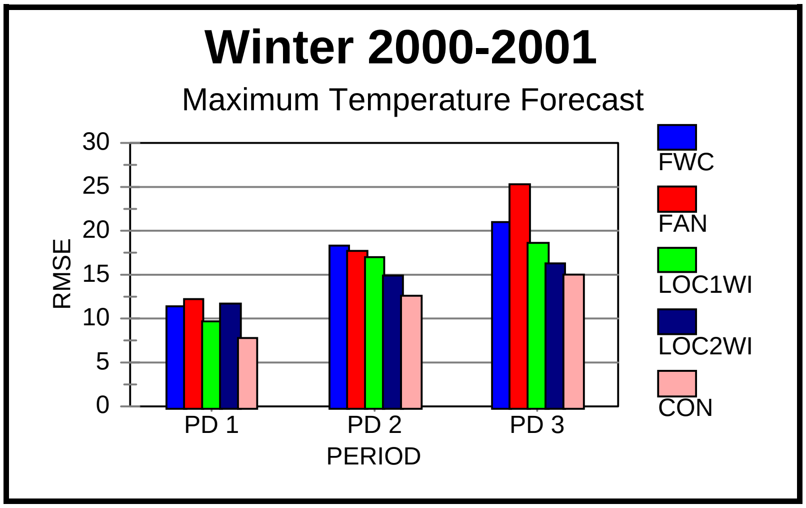


Figure 4. a) Root Mean Squared Error b) Mean Absolute Error c) Bias in degrees Fahrenheit. Maximum Temperatures - Fall (September - November)

a)



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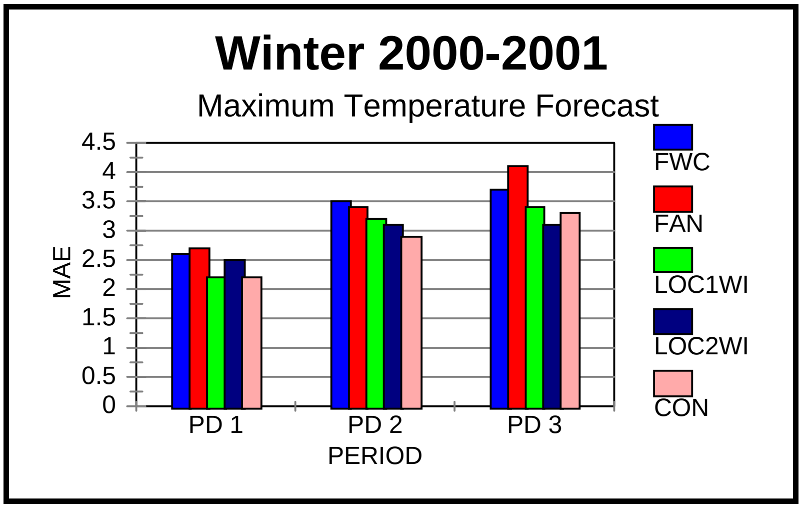

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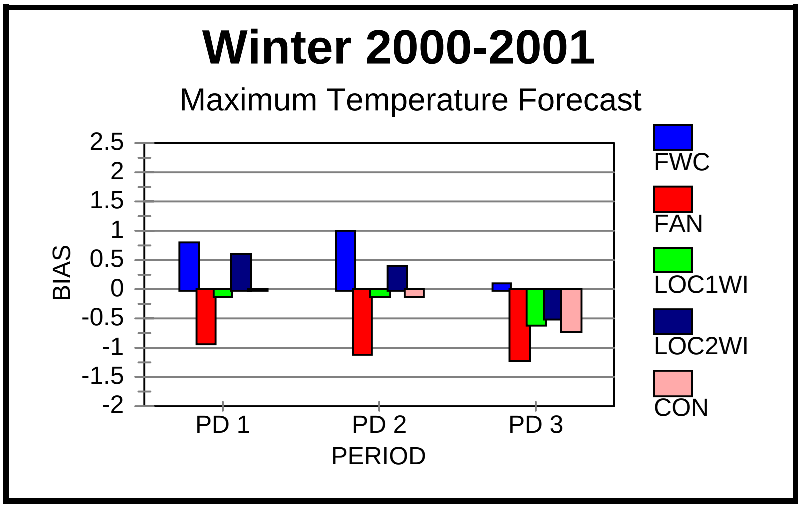
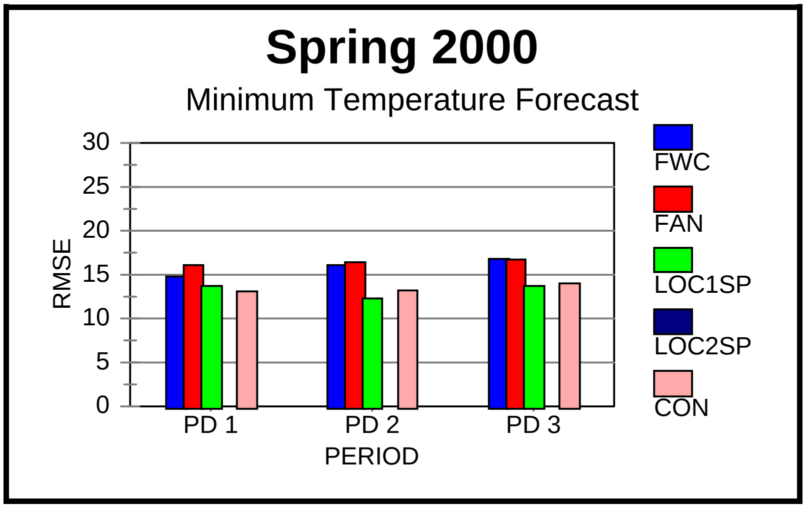


Figure 5. a) Root Mean Squared Error b) Mean Absolute Error c) Bias in degrees Fahrenheit. Maximum Temperatures - Winter (December- February)

a)



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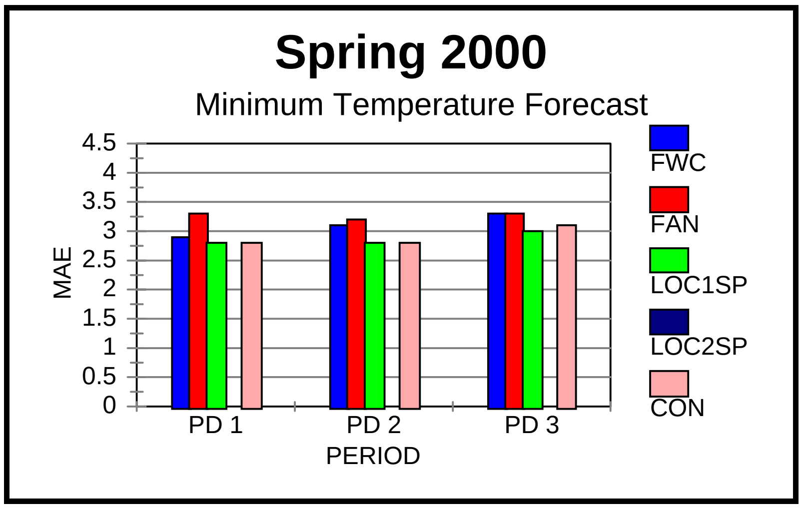


c)

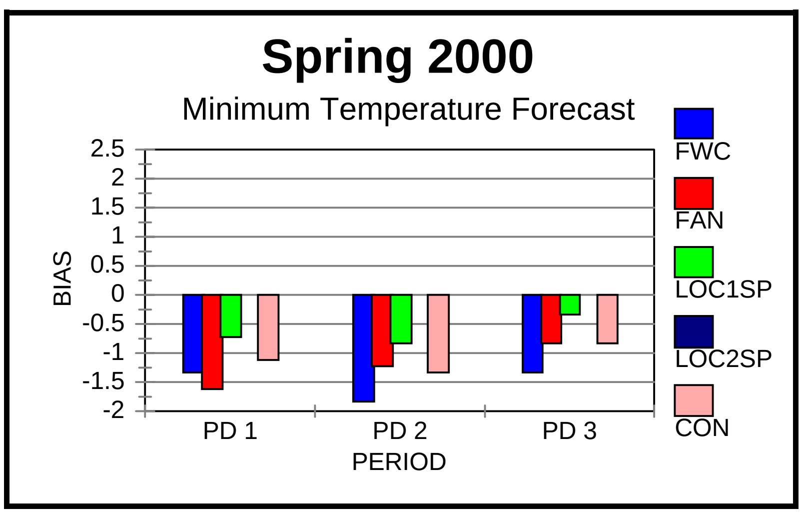


Figure 6. a) Root Mean Squared Error b) Mean Absolute Error c) Bias in degrees Fahrenheit. Minimum Temperatures - Spring (March - May). *Note: LOC2SP minimum temperature scheme was not developed until Summer 2000.*

a)

b)

c)

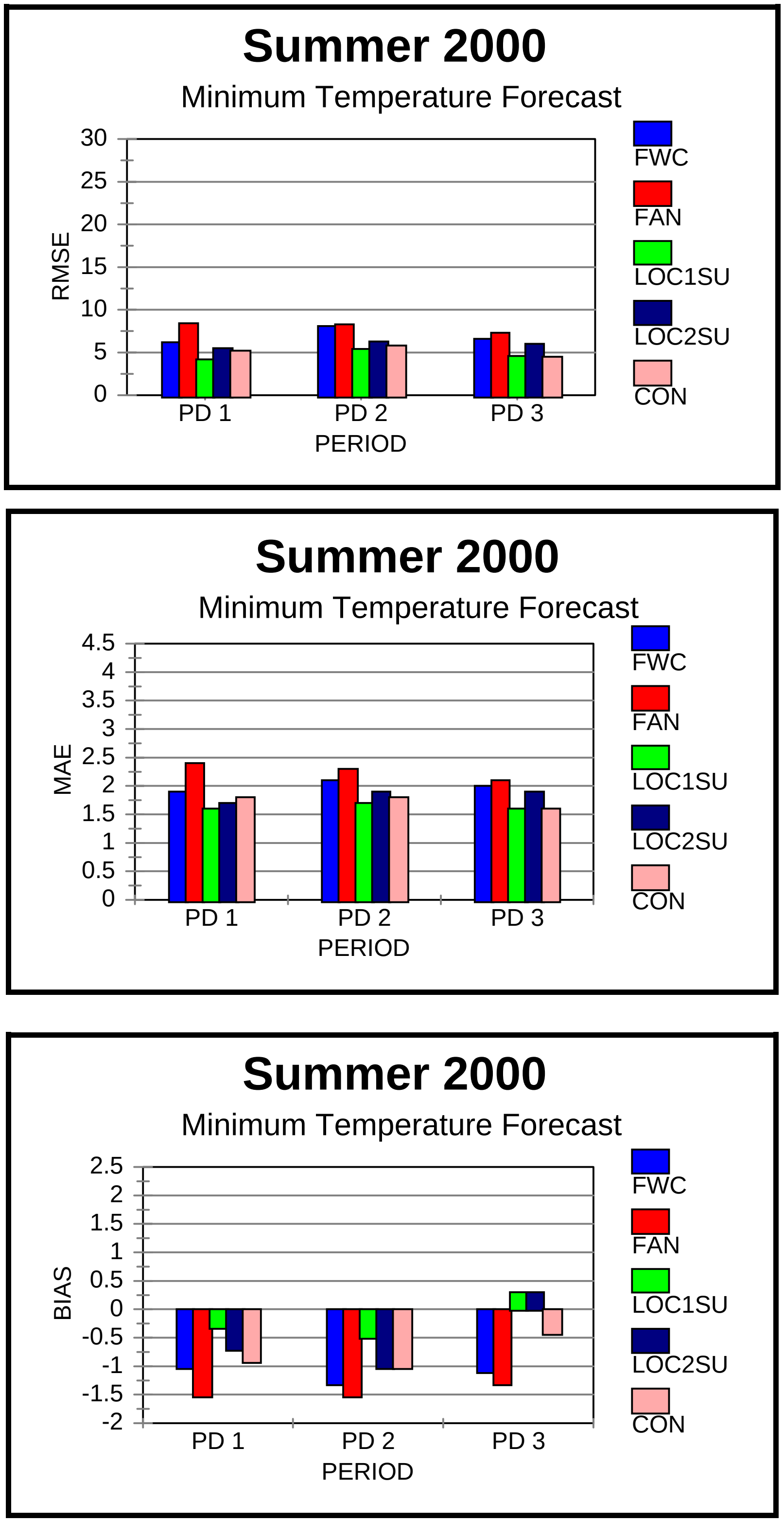
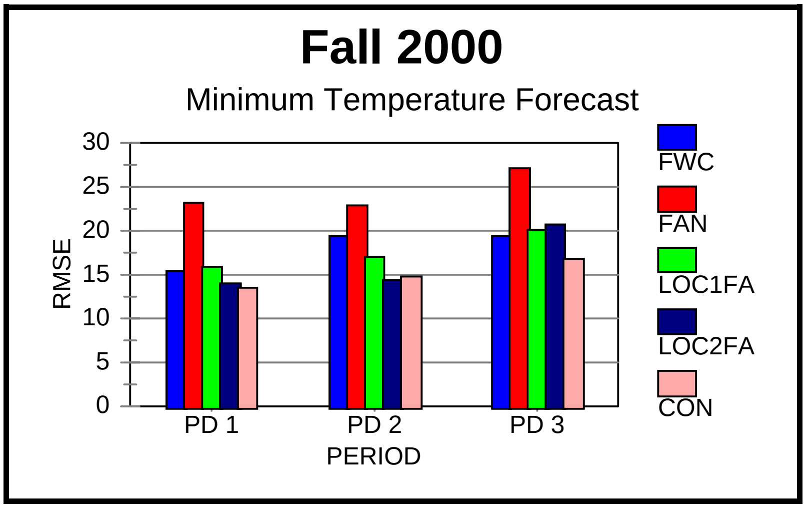
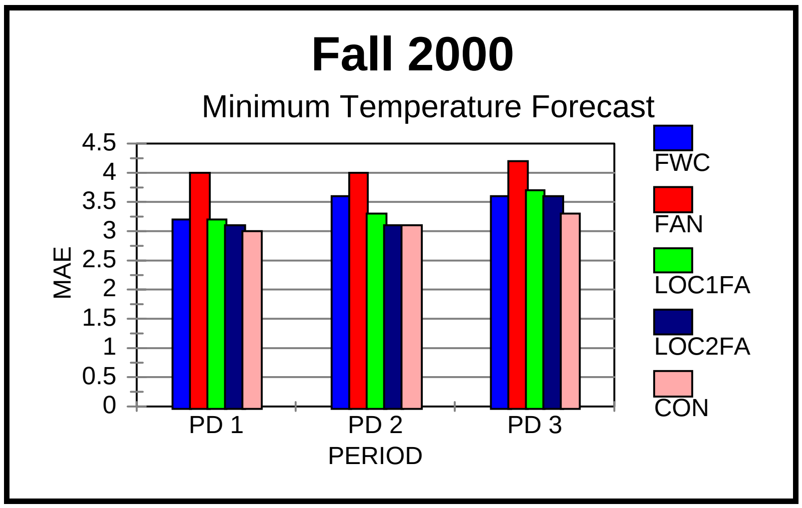


Figure 7. a) Root Mean Squared Error b) Mean Absolute Error c) Bias in degrees Fahrenheit. Minimum Temperatures - Summer (June - August)

a)



b)



c)

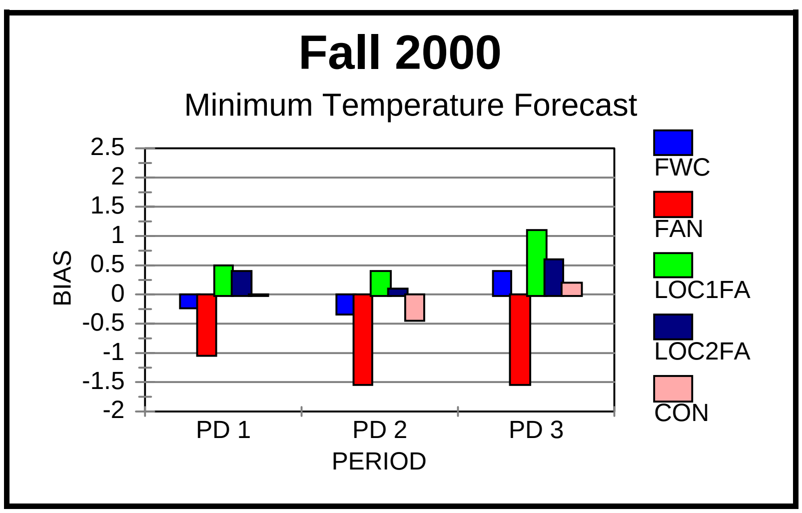
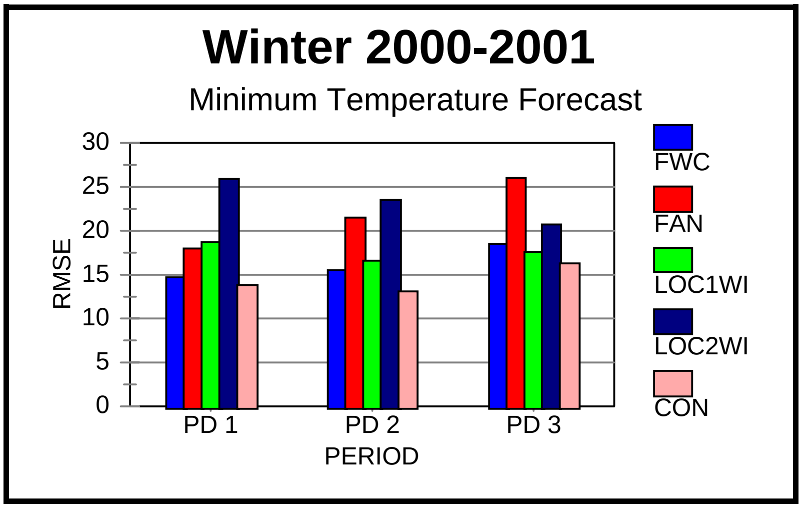
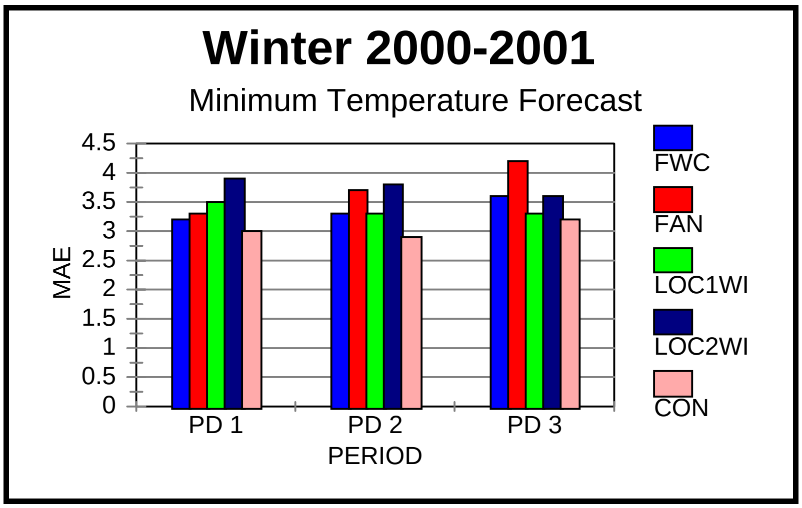


Figure 8. a) Root Mean Squared Error b) Mean Absolute Error c) Bias in degrees Fahrenheit. Minimum Temperatures - Fall (September - November)

a)



b)



c)

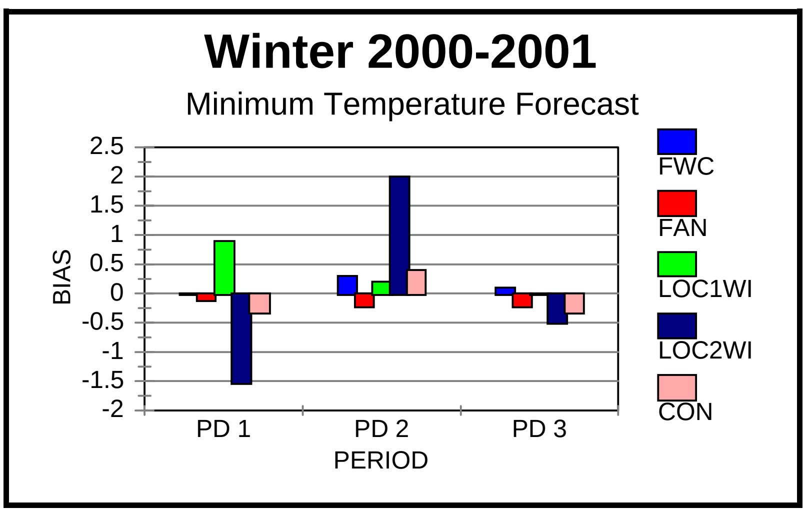


Figure 9. a) Root Mean Squared Error b) Mean Absolute Error c) Bias in degrees Fahrenheit. Minimum Temperatures - Winter (December - February)

APPENDIX II

Local Temperature Equations

Spring Season March through May

0000 UTC cycle

24-h max (LOC) = 0.5604(fwc) + 1.1465(dew954) + 0.5034(vwdbl5) - 0.4234(vwd955) + 0.5413(ttbly) - 1.0352(tdbly) + 21.9253

24-h max (ETA) = -0.0957(relbl1) + 0.0656(uwdbl1) + 0.4373(dew954) + 0.6172(vwdbl5) - 0.4089(vwd955) + 2.0367(cosday) + 1.1632(ttbly) - 0.0532(r8570) - 0.6405(av10m) + 57.7013

36-h min (LOC) = 0.7503(fwc) + 0.0598(vwdbl2) + 0.4599(tmp2m) + 7.5298

36-h min (ETA) = No equation

48-h max (LOC) = 0.6253(fwc) + 0.2616(tmp955) - 1.6925(cosday) + 0.4597(tdbly) - 0.1777(rhbly) + 29.2957

48-h max (ETA) = 0.0558(uwd951) - 1.7277(tmp2m4) + 1.2814(tmp955) - 10.5451(pcpn06) + 5.5375(ttbly) - 3.8190(tt975) + 0.4063(tt850) - 4.1269(tdbly) + 4.0750(td975) + 0.0039(uvv87) + 52.5660

1200 UTC cycle

24-h min (LOC) = 0.6634(fwc) + 0.0969(spd953) - 5.7302(pcpn06) + 0.6551(tmp2m) + 7.8388

24-h min (ETA) = No equation

36-h max (LOC) = 0.6459(fwc) + 0.5217(tmp955) - 8.1250(pcpn06) + 0.1894(av10m) + 17.5172

36-h max (ETA) = 0.10743(uwdbl1) + 3.3058(ttbly) - 2.1951(tt975) + 0.5709(tt850) + 0.0057(uvv87) + 45.3718

48-h min (LOC) = 0.7081(fwc) + 0.5868(tmp2m) + 8.1292

48-h min (ETA) = No equation

Summer Season June through August

0000 UTC cycle

24-h max (LOC) = 0.6589(fwc) + 0.5569(tmp953) - 1.8900(cosday) -2.1920(tdbly) + 2.1777(td975) + 19.0209

24-h max (ETA) = 1.1926(tmp953) - 1.5358(cosday) + 0.5004(tt850) + 0.0042(uvv87) - 0.1409(asp10) + 55.8621

36-h min (LOC) = 0.5447(fwc) + 0.3021(tdd2m) + 0.6716(td900) - 0.1212(r9585) + 0.2164(asp10) + 24.2798

36-h min (ETA) = -0.0350(uwdbl4) - 1.9320(tt875) + 1.8229(tt850) + 0.5755(tdd2m) + 1.0175(td925) + 0.5221(td850) - 0.2943(r9585) + 0.0366(r7050) + 0.2819(asp10) + 59.7828

48-h max (LOC) = 0.6249(fwc) + 0.5945(tmp2m3) - 3.2758(cosday) + 0.2360(au10m) + 17.5434

48-h max (ETA) = 0.1227(uwd953) + 1.0725(tmp953) - 4.0899(cosday) + 2.9966(ttbly) - 2.9688(tt975) + 0.5782(tt850) + 0.0041(uvv87) + 53.0805

1200 UTC cycle

24-h min (LOC) = 0.5254(fwc) + 0.2687(dew954) + 0.3973(tmp2m) + 0.3468(tt850) + 14.4575

24-h min (ETA) = 0.2817(dew954) + 1.0050(tt850) + 0.6597(tdd2m) + 0.0765(r9550) + 30.7159

36-h max (LOC) = 0.6372(fwc) + 0.5489(tmp953) - 2.2895(cosday) - 3.9475(tdbly) + 3.9726(td975) + 21.7283

36-h max (ETA) = 1.2552(tmp953) + 0.0880(uwd955) - 3.3762(cosday) + 3.2446(ttbly) - 3.5505(tt975) + 0.7722(tt850) - 4.3462(tdbly) + 4.3147(td975) + 0.0049(uvv87) + 55.5739

48-h min (LOC) = 0.5910(fwc) + 0.9351(tdbly) - 0.1410(rhbly) + 0.4103(asp10) + 20.6098

48-h min (ETA) = 0.4048(tmp2m) + 0.7333(tt850) + 0.8521(tdbly) - 0.1093(td925) + 0.0802(rhbly) + 0.5033(asp10) + 33.4441

Fall Season September through November

0000 UTC cycle

24-h max (LOC) = 0.6014(fwc) + 0.8302(ttbly) - 0.1689(td925) + 0.0709(r9585) - 0.0326(r9550) + 11.1961

24-h max (ETA) = -0.0925(rsf851) + 2.7700(cosday) + 1.7029(tdbly) - 0.3809(rhbly) + 85.8533

36-h min (LOC) = 0.6367(fwc) + 0.3556(tmp953) + 0.3894(tmp2m) + 0.0368(r8570) + 0.3384(asp10) + 5.8925

36-h min (ETA) = 1.0607(tmp953) + 4.3799(cosday) + 1.0562(ttbly) - 1.1384(tt975) + 0.5959(tdd2m) + 0.1082(r9550) + 0.3380(asp10) + 26.4850

48-h max (LOC) = 0.5399(fwc) - 0.0448(relbl2) + 0.7758(ttbly) + 22.4686

48-h max (ETA) = -0.0714(rsf851) + 0.6353(tmp955) + 3.1719(cosday) + 0.8770(ttbly) + 53.8055

1200 UTC cycle

24-h min (LOC) = 0.7308(fwc) + 0.0789(vwdbl2) + 0.5204(tmp2m) + 0.2340(asp10) + 7.4110

24-h min (ETA) = 0.5314(tmp952) + 0.3192(dew952) + 5.0888(cosday) + 0.5856(tdd2m) + 0.1069(r9550) + 32.1472

36-h max (LOC) = 0.6096(fwc) + 0.6634(tmp2m4) + 14.2016

36-h max (ETA) = -0.0656(rsf851) + 0.6964(tmp955) + 2.9607(cosday) + 2.3410(ttbly) - 1.4776(tt975) + 50.0588

48-h min (LOC) = 0.5604(fwc) + 0.4965(tmp951) + 0.3673(tmp2m) + 0.0533(r8570) + 0.2998(asp10) + 7.0644

48-h min (ETA) = 0.9503(tmp951) + 0.4079(dew951) + 6.1909(cosday) + 0.1559(r9550) + 28.4966

Winter Season December through February

0000 UTC cycle

24-h max (LOC) = 0.6945 (fwc) + tmp2m4(.6380) + 9.9501

24-h max (ETA) = 1.5249(dew2m4) + .4325(tt900) - .4114(rhbly) + 0.0070(uvv87) + 74.8825

36-h min (LOC) = Exp[.0165(fwc) + 0.0190(tmp953) + 0.0104(tmp2m) - 0.0139(tt975) + 0.0026(td850) + 2.8932]

36-h min (ETA) = Exp[0.0044(k10852) + 0.0167(tmp953) + 0.0710(cosday) + 0.0086(tmp2m) -0.0129(tt975) - 0.0097(tt900) + 0.0091(tdbly) + 0.005(td850) + 0.0010(r7050)]

48-h max (LOC) = 0.5473(fwc) - 0.0589(rsf852) + 0.9283(tdbly) - 0.2176(rhbly) + 0.1046(r8570) - 0.0974(r9550) + 40.7684

48-h max (ETA) = -0.1660(rsf852) + 4.4362(cosday) + 1.3997(ttbly) + 0.3776(tt850) + 0.0957(r9585) + 0.1063(r8570) - 0.1395(r9550) + 0.0052(uvv87) + 52.9586

1200 UTC cycle

24-h min (LOC) = Exp[0.0179(fwc) + 0.0021(k10852) + 0.0158(tmp2m) - 0.0102(ttbly) + 0.1285]

24-h min (ETA) = Exp[0.0022(k10852) + 0.0185(tmp953) + 0.0192(tmp2m) - 0.0156(tt975) + 0.0064(td975) + 0.0012(r8570) + 0.4303]

36-h max (LOC) = $[0.0405(fwc) + 0.0228(tmp955) + 0.0240(td975) - 0.0066(rhbly) + 0.0002(uvv87) + 5.4239]^2$

36-h max (ETA) = 0.0542(uwd951) - 0.0497(rsf852) + 0.6641(tmp955) + 5.5838(cosday) + 1.7137(ttbly) - 0.9334(tt975) + 0.2959(tt850) + 0.0065(uvv87) + 51.2152

48-h min (LOC) = $[0.0494(fwc) - 0.0051(uwdbl1) + 0.0525(tmp953) + 0.0379(tmp2m) - 0.0334(tt975) + 0.0120(asp10) + 3.8343]^2$

48-h min (ETA) = Exp[0.0055(k10852) + 0.0750(cosday) + 0.0117(tmp2m) + 0.0013(rhbly) + 0.0021(r9550) + 0.0001(uvv87) + 0.0099(asp10) - 4.0285]

CAD max temperature equation = 1.1980(tmp2m) - 7.4873(pcpn06) + 0.4895(tdbly) + 0.0069(uvv87) + 36.0779

Predictor Key

fwc = NGM MOS max/min temperature (^{o} F)

Eta model sounding predictors:

note: 0000 UTC forecast-	1200 UTC forecast-
projection 1 = data at 12z	projection 1 = data at 00z
projection 2 = data at 15z	projection 2 = data at 03z
projection 3 = data at 18z	projection 3 = data at 06z
projection 4 = data at 21z	projection 4 = data at 09z
projection 5 = data at 00z	projection 5 = data at 12z

tmp2m = 2 meter temperature (^{o} C)
tmp2m3 = 2 meter temperature projection 3 (^{o} C)
tmp2m4 = 2 meter temperature projection 4 (^{o} C)
ttbly = boundary layer temperature (^{o} C)
tt975 = 975 mb temperature (^{o} C)
tmp951 = 950 mb temperature projection 1 (^{o} C)
tmp952 = 950 mb temperature projection 2 (^{o} C)
tmp953 = 950 mb temperature projection 3 (^{o} C)
tmp955 = 950 mb temperature projection 5 (^{o} C)
tt900 = 900 mb temperature (^{o} C)
tt875 = 875 mb temperature (^{o} C)
tt850 = 850 mb temperature (^{o} C)
tdd2m = 2 meter dewpoint (^{o} C)
dew2m4 = 2 meter dewpoint projection 4 (^{o} C)
tdbly = boundary layer dewpoint (^{o} C)
td975 = 975 mb dewpoint (^{o} C)
dew951 = 950 mb dewpoint projection 1 (^{o} C)
dew952 = 952 mb dewpoint projection 2 (^{o} C)
dew954 = 954 mb dewpoint projection 4 (^{o} C)
td925 = 925 mb dewpoint (^{o} C)
td900 = 900 mb dewpoint (^{o} C)
td850 = 850 mb dewpoint (^{o} C)
rhbly = boundary layer relative humidity (%)
relbl1 = boundary layer relative humidity projection 1 (%)
relbl2 = boundary layer relative humidity projection 2 (%)
rsf851 = 850-500 mb relative humidity projection 1 (%)
rsf852 = 850-500 mb relative humidity projection 2 (%)
r9585 = 950-850 mb relative humidity (%)
r9550 = 950-500 mb relative humidity (%)
r8570 = 850-700 mb relative humidity (%)
r7050 = 700-500 mb relative humidity (%)

Predictor Key, cont.

au10m = average u component 10 meter wind (kt)
av10m =average v component 10 meter wind (kt)
asp10 = average 10 meter wind speed (kt)
uwdbl1 = u component boundary layer wind projection 1 (kt)
vwdbl2 = v component boundary layer wind projection 2 (kt)
uwdbl4 = u component boundary layer wind projection 4 (kt)
vwdbl5 = v component boundary layer wind projection 5 (kt)
uwd951 = u component 950 mb wind projection 1 (kt)
uwd953 = u component 950 mb wind projection 3 (kt)
uwd955 = u component 950 mb wind projection 5 (kt)
vwd955 = v component 950 mb wind projection 5 (kt)
spd953 = 950mb wind speed projection 3 (kt)
uvv87 = vertical motion 800-700 mb (u/s)
k10852 = 1000-850mb thickness projection 2 (m)
cosday = cosine of the Julian day
pcpn06 = 6 hr precipitation (in)

Maximum Temperature Forecasts:

	Spring			Summer		
	24-HOUR	36-HOUR	48-HOUR	24-HOUR	36-HOUR	48-HOUR
CON VS FWC	22.2	29.0	23.3	27.3	17.4	26.9
CON VS FAN	36.4	35.3	23.3	27.3	13.6	24.0
CON VS LOC1	4.5	8.3	8.0	15.8	17.4	13.6
CON VS LOC2	12.5	18.5	0.0	33.3	34.5	20.8
FWC VS FAN	18.2	8.8	0.0	0.0	-4.3	-3.8
FWC VS LOC1	-18.5	-22.6	-16.7	-13.6	0.0	-15.4
FWC VS LOC2	-11.1	-12.9	-23.3	8.3	20.7	-7.7
FAN VS LOC1	-33.3	-29.4	-16.7	-13.6	4.3	-12.0
FAN VS LOC2	-27.3	-20.6	-23.3	8.3	24.1	-4.0
LOC1 VS LOC2	8.3	11.1	-8.0	20.8	20.7	8.3

	Fall			Winter		
	24-HOUR	36-HOUR	48-HOUR	24-HOUR	36-HOUR	48-HOUR
CON VS FWC	14.3	17.4	12.5	15.4	17.1	10.8
CON VS FAN	28.0	34.5	22.2	18.5	14.7	19.5
CON VS LOC1	10.0	5.0	4.5	0.0	9.4	2.9
CON VS LOC2	21.7	5.0	12.5	12.0	6.5	-6.1
FWC VS FAN	16.0	20.7	11.1	3.7	-2.9	9.8
FWC VS LOC1	-4.8	-13.0	-8.3	-15.4	-8.6	-8.1
FWC VS LOC2	8.7	-13.0	0.0	-3.8	-11.4	-16.2
FAN VS LOC1	-20.0	-31.0	-18.5	-18.5	-5.9	-17.1
FAN VS LOC2	-8.0	-31.0	11.1	-7.4	-8.9	-24.4
LOC1 VS LOC2	13.0	0.0	8.3	12.0	-3.1	-8.8

Table 1. Percent improvement for maximum temperature forecasts, stratified by season and forecast range. 95 percent significance level improvements are shaded.

Minimum Temperature Forecasts:

	Spring			Summer		
	24-HOUR	36-HOUR	48-HOUR	24-HOUR	36-HOUR	48-HOUR
CON VS FWC	3.4	9.6	6.1	5.3	14.3	20.0
CON VS FAN	15.2	12.5	6.1	25.0	21.7	23.8
CON VS LOC1	-3.6	0.0	-3.2	-11.1	-5.6	0.0
CON VS LOC2	N/A	N/A	N/A	-5.6	5.3	15.8
FWC VS FAN	12.1	3.1	0.0	20.8	8.7	4.8
FWC VS LOC1	-6.9	-9.7	-9.1	-15.8	-19.0	-20.0
FWC VS LOC2	N/A	N/A	N/A	-10.5	-9.5	-5.0
FAN VS LOC1	-18.2	-12.5	-9.1	-33.3	-26.1	-23.8
FAN VS LOC2	N/A	N/A	N/A	-29.2	-17.4	-9.5
LOC1 VS LOC2	N/A	N/A	N/A	5.9	10.5	15.8

	Fall			Winter		
	24-HOUR	36-HOUR	48-HOUR	24-HOUR	36-HOUR	48-HOUR
CON VS FWC	6.3	13.9	8.3	6.3	12.1	11.1
CON VS FAN	25.0	22.5	21.4	9.1	21.6	23.8
CON VS LOC1	6.3	6.1	10.8	14.3	12.1	3.0
CON VS LOC2	3.2	0.0	8.3	23.1	23.7	11.1
FWC VS FAN	20.0	10.0	14.2	3.0	10.8	14.3
FWC VS LOC1	0.0	-8.3	2.7	8.6	0.0	-8.3
FWC VS LOC2	-3.1	-13.9	0.0	17.9	13.2	0.0
FAN VS LOC1	-20.0	-17.5	-11.9	5.7	-10.8	-21.4
FAN VS LOC2	-22.5	-22.5	-14.3	15.4	2.6	-14.3
LOC1 VS LOC2	-3.1	-6.1	-2.7	10.3	13.2	8.3

Table 2. Percent improvement for minimum temperature forecasts, stratified by season and forecast range. 95 percent significance level improvements are shaded.